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Improved Waste Cooking Oil with CeO_2 Nanoparticles for Inconel 718 Super Alloys Machining at CNC Turning Center

Ganapati Ramavat[1], **R. Saravanan**[2*], **Balamurugan Subramaniam**[3], **Miguel Escobar**[4], **Edwin Pozo**[4], **Alugoju Uday Kumar**[5] **and T.S. Senthilkumar**[6]

[1]*Department of Mechanical Engineering, Anurag Engineering College, Suryapet, Telangana, India*
[2]*Department of Mechanical Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu, India*
[3]*Department of Mechanical Engineering, K.S.R. Institute for Engineering and Technology, Tiruchengode, Tamil Nadu, India*
[4]*Department of Mechanical Engineering, Facultad de Ingeniería Mecánica, Escuela Superior Politécnica se Chimborazo (ESPOCH), Riobamba, Ecuador*
[5]*Department of Mechanical Engineering, St. Martin's Engineering College, Secunderabad, Telangana, India*
[6]*Department of Mechanical Engineering, K. Ramakrishnan College of Technology, Trichy, Tamil Nadu, India*

[*]Correspondence to:
R. Saravanan
Department of Mechanical Engineering,
Saveetha School of Engineering,
Saveetha Institute of Medical and Technical Sciences,
Saveetha University,
Chennai, Tamil Nadu, India.
E-mail: dr.sarravanan@gmail.com

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Abstract

Nanofluids are extensively utilized in metal machining operations. In contemporary times, there has been a notable surge in the utilization of challenging-to-cut materials. This trend is primarily driven by the need to enhance the dependability of critical products operating under elevated temperatures, while also minimizing wear and maximizing strength. Traditionally, the machining of such materials necessitated the implementation of specialized machining processes. However, the process of mass production is characterized by its time-consuming nature and its propensity to significantly escalate manufacturing expenses. To address these challenges, the present study has opted for the utilization of computer numerical control (CNC) machining, specifically focusing on CNC turning centers. The cooling process assumes a crucial role due to the high cutting velocity and utilization of much harder tools in this specific procedure. In this study, the utilization of preferred refined waste cooking oil (WCO) as the primary fluid and the incorporation of cerium dioxide (CeO_2) nanoparticles as additives to enhance cooling effects were examined. Additionally, other crucial factors such as spindle speed, tool feed rate, and depth of cut were considered to optimize material removal rate (MRR) that is maximize MRR during the finishing process of the components. The Taguchi method was utilized. The findings indicated that the process parameters that yielded the best results were a spindle speed of 3000 rpm, a feed rate of 0.15 mm per revolution, a depth of cut of 0.04 mm, and a refined WCO oil with a CeO_2 concentration of 1 wt.%.

Keywords

Coolant, CNC turning, Waste cooking oil, Nanofluids, Nanoparticles

Introduction

The aerospace, automotive, and defence sectors all make extensive use of Inconel 718. Inconel 718 is used to manufacture a wide variety of different items, such as fasteners (nuts, bolts, flanges, threaded fittings, screws, socket weld fittings, gas turbine blades, etc.).

During production, machining operations are frequently necessary for these goods. But Inconel 718 has a reputation for being tough to manufacture. This is due to the fact that there are a number of difficulties that arise when machining this alloy. As a result, Inconel 718 is considered to have poor machinability. Inconel 718 is not recommended for dry machining. The feasibility of using modified minimum quantity lubrication (MQL) or nanofluid MQL techniques to enhance Inconel 718's machining performance is investigated. In the following sections, we will discuss the most up-to-date findings from studies conducted in the past that assess Inconel 718's machinability.

Dry turning tests were performed on Inconel 718 using uncoated and coated cemented carbide tools. The authors investigated how cutting pressures and tool life changed as a result of varying machining factors (cutting velocity, feed rate, and depth-of-cut). It was determined that cutting depths greater than 1 mm necessitate the use of a coated tool. Surface integrity of finish-turned Inconel 718 was studied at how jet pressure and cutting fluid jet direction affected the material. A considerable decrease in tensile residual stresses was reportedly brought about by ultra-high-pressured cutting fluid.

Physical vapor deposition (PVD) TiN-coated carbide inserts and chemical vapor deposition TiN-coated carbide inserts were used to study the machinability properties of Inconel 718 by Rahman et al. [1]. Surface roughness, flank wear on the cutting tool, and cutting forces were all taken into account to determine machinability. Cutting speed, feed rate, and the angle of the side cutting edge were found to be significant factors in determining the durability of the tool.

High speed machining of Inconel 718 was studied by [2], specifically its heat effects. Up to a cutting speed of 600 m/min, researchers measured the temperature of the cutting zone and the amount of tool wear. Cutting tool notch wear was found to be facilitated by the abrasion mechanism. Experiments in machining Inconel 718 with a PVD TiCN/Al_2O_3/TiN-coated carbide tool were performed by [3] up to a cutting velocity of 50 m/min. The authors experimented with cutting fluid pressures between the low and high ends of the spectrum, reaching a maximum of 203 bar. Machined surfaces were smoother, and the tool life was extended by more than seven hundred and forty percent thanks to the high-pressure supply of cutting fluid. Using a ceramic tool of two different geometries (round and square), investigated how cutting speed affected tool wear and tool life when turning Inconel 718 with pressured cutting fluid (water). At lower cutting velocities, it was found that a square-shaped tool exhibited little flank wear. However, for a round-type insert, cutting at a higher range of velocities resulted in reduced flank wear. Inconel 718 in a cryogenic state using an uncoated carbide insert, comparing its machinability to that of dry machining and MQL. Cutting forces were found to be greater during dry machining experiments. Built-up-edge was created under MQL to a smaller extent at the outset of machining compared to dry well and cryogenic chilling conditions. The tool wear rate under MQL was initially comparable to that under cryogenic cooling (up to 150 sec of machining time), then rose under MQL, and finally seemed comparable to that under dry machining. Experiments in MQL turning were performed on Inconel 718, used coated carbide tools with cutting velocities ranging from 60 to 90 m/min. Dry and wet machining were evaluated in terms of how effectively they cut. Criteria for machinability included how long tools would last and how smooth the surface would be when compared to PVD TiN/AlN superlattice and PVD TiAlN-coated inserts, the TiCN/Al_2O_3/TiN-coated insert performed better. During machining, carrier gas was discovered to play a crucial function in delivering cooling benefits. In addition, roughing the tool's worn flank face allowed for a higher machinable surface finish to be achieved under MQL. Using a micro-liter lubrication range (flow rate 1 ml/h) and a coated carbide tool, Cover-type nozzles to direct a fine stream of concentrated lubricant into the cutting area. Tool longevity was used as a proxy for machining efficiency. Based on the findings, the MQL process is more efficient and productive when lubricants are delivered in a concentrated stream. End milling Inconel 718 with coated tools in a dry and vegetable oil (Bescut 173)-based MQL environment was investigated, who analyzed tool wear and cutting forces. Tool life was increased by 1.57 times while using MQL compared to dry cutting. In addition to reducing cutting forces, MQL was shown to increase friction at the tool-chip and tool-work interfaces. Tool wear was reduced by MQL because the cutting fluid was so effective at keeping the cutting edge cool and lubricated.

The primary objective of this study is to address the current research gap regarding the machining of Inconel 718. Specifically, the study aims to explore the use of CeO_2 nanofluid in combination with refined WCO oil in a flood cooling environment. The ultimate goal is to improve the MRR during the machining process. The aim of this study is to fabricate a nanofluid by incorporating CeO_2 nanoparticles at different concentrations. To ascertain the scope of variables, a series of trial runs will be executed employing the L16 orthogonal array experimental design. To improve the rate at which material is removed, it is imperative to optimize various parameters, such as the concentrations of nanoparticles. Confirmation experiments were conducted to validate the accuracy of the predicted process parameters.

Materials and Method

The standard work materials were procured from Chennai Metals (Tamil Nadu, India). It is recommended that the workpieces be divided into segments measuring 40 mm in length. The measured diameter of the rod was 16 mm. The wire-cut electric discharge machine was utilized to perform the cutting process. The procedure for synthesizing the nanofluid involved the amalgamation of purified WCO with CeO_2 nanoparticles at different concentrations, specifically 0.25 wt.%, 0.5 wt.%, 0.75 wt.%, and 1 wt.%. Hence, a total of four unique cutting fluids were formulated. Each type of nanofluid is produced using a quantity of 1 kg of refined WCO. The experiments were conducted utilizing a CNC turning center. A series of preliminary trials were conducted to address the numerous variables. Table 1 provides a comprehensive representation of the different variables, including their corresponding ranges and levels.

The present study employed the L16 orthogonal array to manipulate four factors, specifically the coolant grades, which were systematically varied at four distinct levels in ascending order. The Taguchi experimental design is presented in table 2. The coolant's flow rate was determined to be 4 L/min. The decision was made taking into account the absence of fuming conditions, in order to guarantee the efficient elimination

Table 1: Machinability assessment of Inconel 718 work materials by examining a range of variables and their corresponding levels.

Factor	Levels	Values
Spindle speed (rpm)	4	1200, 1800, 2400, 3000
Feed rate (mm/rev)	4	0.05, 0.10, 0.15, 0.20
Depth of cut (mm)	4	0.01, 0.02, 0.03, 0.04
CeO_2 concentration (wt.%)	4	0.25, 0.50, 0.75, 10.00

Table 2: The experimental design and observations of MRR in machining Inconel 718.

Exp. No.	Spindle speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)	CeO_2 concentration (wt.%)	MRR
1	1200	0.05	0.01	0.25	0.246855
2	1200	0.1	0.02	0.5	1.139536
3	1200	0.15	0.03	0.75	2.175146
4	1200	0.2	0.04	10	2.801614
5	1800	0.05	0.02	0.75	1.373273
6	1800	0.1	0.01	10	1.916188
7	1800	0.15	0.04	0.25	4.027970
8	1800	0.2	0.03	0.5	2.994188
9	2400	0.05	0.03	10	4.016050
10	2400	0.1	0.04	0.75	5.278804
11	2400	0.15	0.01	0.5	3.032276
12	2400	0.2	0.02	0.25	2.016545
13	3000	0.05	0.04	0.5	5.903858
14	3000	0.1	0.03	0.25	3.663373
15	3000	0.15	0.02	10	4.492981
16	3000	0.2	0.01	0.75	2.523303

Figure 1: Machinability investigation facility of CNC turning center at SIMATS University.

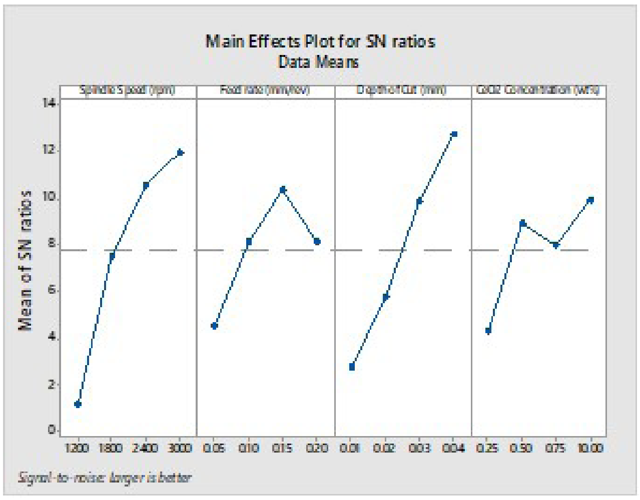

Figure 2: Taguchi analysis results in terms of effects of means of S/N ratios yielded by the different factors and their levels for the MRR observations.

of machined chips and facilitate lubrication to improve the shearing process. The nanofluids demonstrated a desirable level of homogeneity, as indicated by the lack of substantial sedimentation observed following a 48-h storage period in the beaker. The experiments were carried out at the CNT turning center, as illustrated in figure 1. The researchers observed the average MRR during the machining of each specimen and subsequently recorded the corresponding values. The recorded observations for each experiment are displayed in the final column of table 2. The MRR can be calculated by dividing the loss of weight of the material by its density. The weight loss of the material was determined by calculating the difference between its weight before machining and its weight after machining. It is worth noting that the density of the work material is 8.17 g/cc.

Results and Discussion

The investigations were conducted using an orthogonal array in accordance with the Taguchi experimental design. The average MRR was identified as the response variable. Taguchi analysis was utilized to examine the results. The obtained data were entered into Minitab 18, a statistical software program. Table 3 presents the results of the Taguchi analysis of the MRR observation. In table 3, the factors contributing to the influence of machining input rate on high delta-value, which resulted in a value of 5.859, were ranked 3. Similarly, the depth of cut ranked 2 (Delta = 9.938), the concentration of nanofluids ranked 4 (Delta = 5.601), and spindle speed ranked 1 (Delta = 10.777). Table 3 displays a positive correlation between the observed signal to noise (S/N) ratios, indicating that smaller values are preferable. The processing time was 15 sec.

Figure 2 illustrates the benefits of a stronger signal, making a high S/N ratio the recommended choice for the best parameters. The spindle speed significantly affects the improvement of MRR. Particularly, when the spindle speed is adjusted to 1800 rpm, the MRR rapidly falls off. However, it should be noted that when the spindle speed is further increased to 3000 rpm, the MRR afterwards increases dramatically. 3000 rpm is the ideal speed. The ideal feeding circumstance was found to be a feed rate of 0.15 mm per revolution. It was discovered that a cut depth of 0.04 mm and a concentration of 1.0 wt.% were the ideal parameters.

Figure 3 illustrates the consequences of various MRR

Table 3: Results of the Taguchi analysis on the MRR while machining the Inconel 718 surface.

Level	Spindle speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)	CeO_2 concentration (wt.%)
1	1.170	4.526	2.793	4.330
2	7.508	8.128	5.758	8.930
3	10.564	10.384	9.907	7.999
4	11.948	8.151	12.731	9.931
Delta	10.777	5.859	9.938	5.601
Rank	1	3	2	4

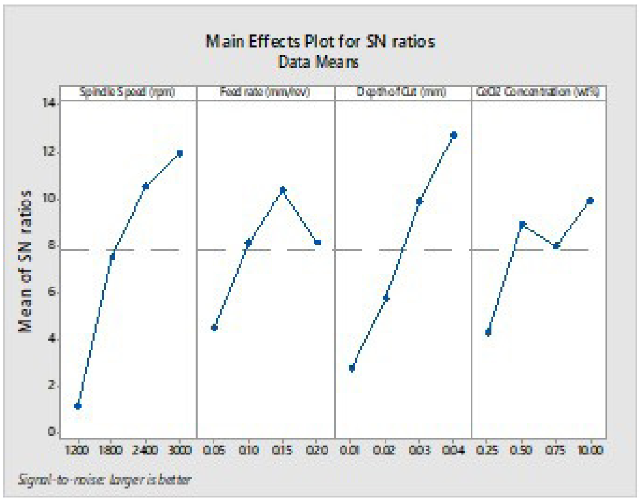

Figure 3: Taguchi analysis results in terms of effects of means of MRR observations at the different factors and their levels.

Table 4: ANOVA results of the MRR observations at the various components.

Source	DF	Adj SS	Adj MS	F-value	p-value
Spindle speed (rpm)	3	15.2716	5.0905	26.02	0.012
Feed rate (mm/rev)	3	1.4823	0.4941	2.53	0.023
Depth of cut (mm)	3	16.0061	5.3354	27.27	0.011
CeO_2 concentration (wt.%)	3	1.8037	0.6012	3.07	0.039
Error	3	0.5870	0.1957	-	-
Total	15	35.1508	-	-	-

Table 5: Findings from the ANOVA for observations of the MRR at various levels of variables.

Term	Coef	SE coef	T-value	p-value	VIF
Constant	2.975	0.111	26.90	0.000	-
Spindle speed (rpm)					
1200	-1.384	0.192	-7.23	0.005	1.50
1800	-0.397	0.192	-2.07	0.013	1.50
2400	0.611	0.192	3.19	0.040	1.50
Feed rate (mm/rev)					
0.05	-0.090	0.192	-0.47	0.037	1.50
0.10	0.024	0.192	0.13	0.027	1.50
0.15	0.457	0.192	2.39	0.047	1.50
Depth of cut (mm)					
0.01	-1.045	0.192	-5.46	0.012	1.50
0.02	-0.720	0.192	-3.76	0.033	1.50
0.03	0.237	0.192	1.24	0.034	1.50
CeO_2 concentration (wt.%)					
0.25	-0.486	0.192	-2.54	0.085	1.50
0.50	0.292	0.192	1.53	0.024	1.50
0.75	-0.137	0.192	-0.72	0.025	1.50

measures. Better here where the mean MRR is at its highest. The minimal mean MRR, which was recorded at 3000 rpm, was higher spindle speed rpm. Similar to this, the ideal processing conditions were 0.15 mm per revolution feed rate, 0.04 mm depth of cut, and 0.75 wt.% concentration.

Two types of analysis of variance (ANOVA) results include those for factors and their levels. The findings of the ANOVA for the MRR observations for variables are presented in table 4. The level of significance is shown by the p-values and the F-values, respectively. Spindle speed (rpm), feed rate (mm/rev), depth of cut (mm), and CeO_2 concentration (wt.%) have the following F-values: 26.02, 2.53, 27.27 and 3.07, respectively. P-values more than 0.1 are considered insignificant, whereas p-values less than 0.05 are considered significant. In light of this, the p-values for spindle speed (rpm), feed rate (mm/rev), depth of cut (mm), and CeO_2 concentration (wt.%) are 0.012, 0.023, 0.011 and 0.039, respectively. The model is sound because all p-values are less than 0.05.

Results of ANOVA for MRR observations at various factor levels are shown in table 5 for the observations. P-values more than 0.1 are considered significant, whereas p-values less than 0.05 are considered significant. Therefore, the p-values for the spindle speeds of 1200, 1800, and 2400 rpm, the feed rates of 0.05, 0.10, and 0.15, the depths of cut (mm), and the CeO_2 concentrations (wt.%) of 0.25, 0.50, and 0.75 were 0.005, 0.013, 0.040, 0.037, 0.027, 0.047, 0.012, 0.033, 0.034, 0.085, 0.024 and 0.025, respectively. Indicating that none of the parameters were significant. These values and the levels that were left out of the tables will not be taken into account for better MRR. A mathematical model to forecast the MRR is shown in equation 1.

MRR = 2.975 – 1.384 Spindle Speed (rpm)_1200 – 0.397 Spindle Speed (rpm)_1800 + 0.611 Spindle Speed (rpm)_2400 + 1.171 Spindle Speed (rpm)_3000 – 0.090 Feed Rate (mm/rev)_0.05 + 0.024 Feed Rate (mm/rev)_0.10 + 0.457 Feed Rate (mm/rev)_0.15 - 0.391 Feed Rate (mm/rev)_0.20 – 1.045 Depth of Cut (mm)_0.01 – 0.720 Depth of Cut (mm)_0.02 + 0.237 Depth of Cut (mm)_0.03 + 1.528 Depth of Cut (mm)_0.04 – 0.486 CeO_2 Concentration (wt.%)_0.25 + 0.292 CeO_2 Concentration (wt.%)_0.50 – 0.137 CeO_2 Concentration (wt.%)_0.75 + 0.332 CeO_2 Concentration (wt.%)_10.00 (1)

The method shown in figure 4 allows for the observation and validation of the model. The residuals of the observed data points are shown in the display. The graph shows that all observations are accurate and that no mistakes have been found. The R-squared value generated by the model was 98.70%, above the required value of 95%. As a result, applying the model to the problem domain is appropriate. A great degree of reliability is shown by the statistical model. The prediction

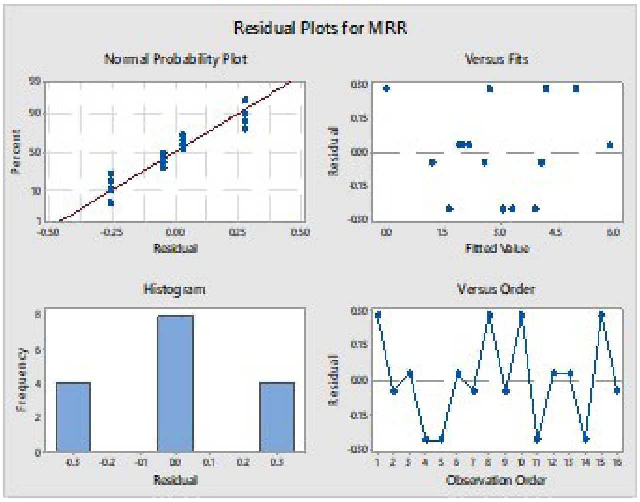

Figure 4: The residuals of MRR observations.

model shows strong agreement with empirical results. Validation confirmation is not required.

Conclusions

The preparation of nanofluids for use as cutting fluids during the machining of Inconel 718 work material inside a CNC turning center was the focus of the current investigation. A total of 16 samples were put through machining procedures using various arrangements of the input parameters. The MRR that resulted was then assessed to establish the average MRR. Statistical methods like Taguchi analysis are used to achieve optimization. The conclusions listed below can be considered.

- To determine whether it would be possible to machine Inconel 718 under flood cooling conditions, an experimental examination was carried out.
- A very high amount of material removal is shown by the MRR.
- The variables considered in this study, such as CeO_2, feed rate, depth of cut, and spindle speed, have a big effect on MRR. Particularly, it was discovered that the feed rate and depth of cuts were significantly influenced, as shown by the fact that their p-values were less than 0.05.
- The observations were error-free and showed statistical validity.
- The experimental results and the mathematical model that was created for prediction showed strong agreement.

Acknowledgements

None.

Conflict of Interest

None.

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